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Diet and Discrepancy Between Tooth and Jaw Size in the Yin-Shang Period of China

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ABSTRACT Tooth to denture base discrepancy (the discrepancy) is the difference between the dental arch length and the sum of crown diameters of teeth in the jaw, a concept which was originally developed in orthodontics. Since the cause-effect relationship between a soft diet and the discrepancy has been demonstrated, the size of the discrepancy should indicate the amount of load on the masticatory system from chewing foods in jaws from archaeological periods. The dietary condition of 71 citizens compared to that of 186 slaves from the Yin-Shang period of China was reconstructed through a study of the discrepancy.

The prevalence of the discrepancy in the Yin-Shang period was around 15%, almost the same as it was during the later Jomon to Yayoi (3000–2000 BP) periods, when rice agriculture was introduced into Japan, and also the same as for present-day pastoralists around Lake Turkana, Kenya. Although the frequency of the discrepancy was slightly higher in male citizens, there were no significant differences in the frequencies between male citizens and female citizens or slaves. The differences in diet may not have been fundamental since the Yin-Shang period would be at the very beginning of the age in which differences of diet according social class began to appear, with implications for the load on the masticatory system. At that time agriculture may not been sufficiently intensified in variety or quantity to have produced a differentiation of the diet between social classes. Am J Phys Anthropol 103:497–505, 1997.

The tooth to denture base discrepancy was originally a concept that was developed for the purpose of orthodontic diagnosis. Angle (1907) disapproved of permanent tooth extractions for orthodontic treatment, and this advice was followed by orthodontists for a long time. Almost four decades later, Tweed (1944, 1945) brought about a change in this view by displaying more than 100 cases which could not have been successfully treated without the extraction of permanent teeth. He proposed a diagnostic measure of the insufficiency of dental arch length compared to the sum of the mesiodistal crown diameter of the teeth in the jaws, and named this the "tooth to denture base discrepancy" (the discrepancy). Today, the discrepancy has serious pathogenic influences on dental disorders, including malocclusion, and prob-

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lems involving both the wisdom teeth and the second molars (Inoue, 1993). It also contributes to the increase of dental caries and periodontitis (Kuo, 1983; Sakashita, 1993).

Although the discrepancy is observed among mammals such as dogs and raccoons (Shigehara, 1988; Kondo et al., 1991), it occurs most commonly in human beings. Previous studies of the etiology of the discrepancy showed that its prevalence increases because the morphological reduction of the human masticatory system is progressing very rapidly, while tooth size has slightly increased (Inoue et al., 1986). In Japan, the frequency of the discrepancy increased from 8.9% in the later Jomon period (Japanese neolithic age, 3000–2000 B.P.) to 43.8% in the Yedo era (400–100 B.P.) (Hanihara et al., 1981). Over this period in Japan, there have also been changes in the jaw bones, involving a reduction in the size of the mandibular ramus and body, an increase in the gonial angle, and a more forward inclination of the maxillary and mandibular incisors, while the size of the facial cranium has not significantly changed (Shiono et al., 1982; Kamegai et al., 1982).

Inoue et al. (1986) proposed that the discrepancy was caused by a reduction of the amount of chewing activity because the food consumed was overly processed and soft. Adaptation to insufficient load would yield a reduced masticatory system. A cause-effect relationship between diet and the discrepancy has been demonstrated on many occasions—for example, in Japan, in New Zealand Maori (Kamegai, 1993), and in Kenya (Kuroe et al., 1995). The Japanese data suggest that lessening of the load on the masticatory system is reflected in a higher rate of the discrepancy (Hanihara et al., 1981). This relationship has also been demonstrated experimentally. Several studies on rats reported that insufficient masticatory consistency of the food during the growing process results in underdevelopment of the masticatory system even in the very short term (Watt and Williams, 1951; Beecher and Corruccini, 1981; Ito et al., 1988; Kuroe, 1991).

Thus, evaluation of the discrepancy can provide information on the load imposed on the masticatory system through the chewing of food. In the present study we attempt to clarify dietary conditions during the Yin-Shang period of China and to establish, from the discrepancy and its occlusal aspects, whether there were any dietary differences between two groups, citizens and slaves.

MATERIALS AND METHODS

Materials

Materials for this study comprised 257 skulls of the Yin-Shang period of China. They can be divided into two groups, Citizens and Slaves (Sakashita et al., in press).

Citizens. Seventy-one well-preserved skulls of 42 male and 29 female adults were selected. The skulls are preserved in the Institute of Archaeology, Chinese Academy of Social Science (CASS), Peoples Republic of China. They had been excavated from medium- or small-sized tombs and had usually been buried with some ornaments (Institute of History and Institute of Archaeology, CASS, 1985).

Slaves. Skulls which are considered to be those of slaves were used as the control group. Only skulls presumably detached from the postcranial skeleton at the time of death had been excavated from so-called sacrificial pits in the royal tomb. They belong to a collection of the Institute of History and Philology, Academia Sinica, Taiwan (Institute of History and Institute of Archaeology, CASS, 1985). These skulls were mainly those of males. Given the dearth of female skulls in the collection, 186 male skulls were used in the present study. Data for these skulls are given in Inoue et al. (1992). All the remains represent a people who lived within a period of a 100 years, from 1400 to 1300 BC (Yang, 1986).

Criteria and method of measurement

The discrepancy refers to the insufficiency of the space of the dental arch compared to the total length of all the teeth. In such a condition, 1) teeth erupt on either the buccal or the lingual side, which results in crowding, 2) anterior teeth incline forward, and 3) teeth which erupt later, such as the third molars, do not have the space to erupt

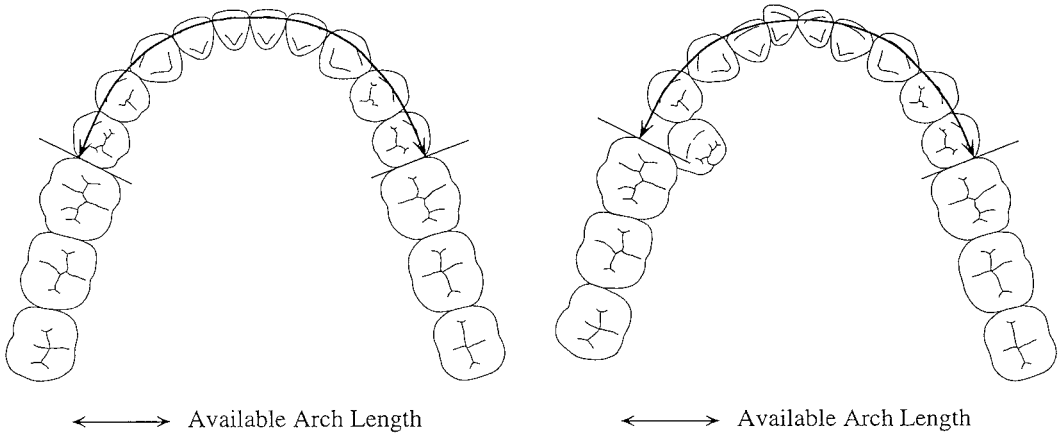

Fig. 1. Measurement of the available arch length (AAL). AAL is measured along the dental arch passing smoothly on the buccal cusps of the premolars and the incisal edge of the front teeth from a mesial proximal surface of the mandibular first molar on one side to the other. The examples show the case of normal occlusion (**left**) and crowded occlusion (**right**).

completely. Thus, the discrepancy can be evaluated using 1) clinical criteria of the discrepancy which is focused on the crowded and impacted teeth and 2) quantitative measurement of the discrepancy which considers the lack of space on the dentition as well as the forward inclination of the teeth.

For the quantitative measurement of the discrepancy Tweed's method (1945) was applied. Although formulas for the diagnosis of the discrepancy have been proposed by several authors, including Tweed (1945), Steiner (1962), and Jarabak and Fizzell (1963), most studies are based on Tweed's method. In his method, the degree of crowding is calculated from the lack of length of available arch length (AAL) compared to required space (RS) mesial to the first molars. Then the degree of forward inclination of the mandibular incisors is calculated and considered. The problem with Tweed's method is that it is focused on the space mesial to the first molar. The positions of the second and third molars are not considered, because in Tweed's time the first molar was thought to be the fundamental tooth for occlusion (Angle, 1907), and orthodontists usually start treatment before the second molars erupt. However, the discrepancy is the disharmony in the size of the whole occlusion, and all teeth should be considered. For this reason, Merrifield (1978) extended Tweed's method to the third molars. If this method were to be applied to the study of skulls, however, very few would be suitable for inclusion since so many teeth are lost postmortem. In addition, there is a significant correlation between the discrepancies obtained following the methods of Tweed and Merrifield (Inoue et al., 1983). Consequently, Tweed's method was selected in the present study for the measurement of the discrepancy.

Clinical criteria of the discrepancy Any skull with a disharmony in size between alveolar bone and the dentition (crowded alignment of the teeth) was classified as a discrepancy case (Inoue et al., 1982).

Measurement of the discrepancy. In order to calculate the tooth to denture base discrepancy, three measurements were carried out: the available arch length (AAL) (Figs. 1, 2), mesio-distal tooth crown diameter of the ten teeth (the incisors, the canines, and the premolars on both sides of the mandible), and the angle of the extension of the dental axis of mandibular central incisors to the Frankfort horizontal (FH) plane (Fig. 3). This last is known as the Frankfort mandibular incisor angle (FMIA) (Tweed, 1945).

The AAL is measured using a piece of unanealed brass wire of about 0.4 mm diam-

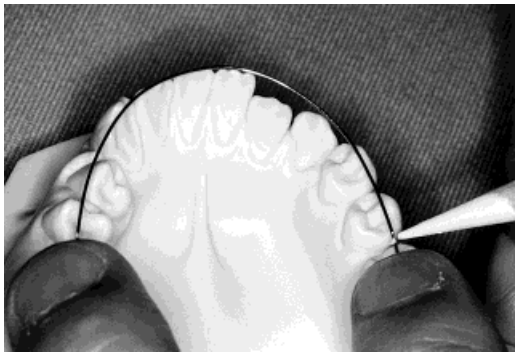

Fig. 2. Available arch length (AAL) was measured using a piece of annealed brass wire along the dental arch.

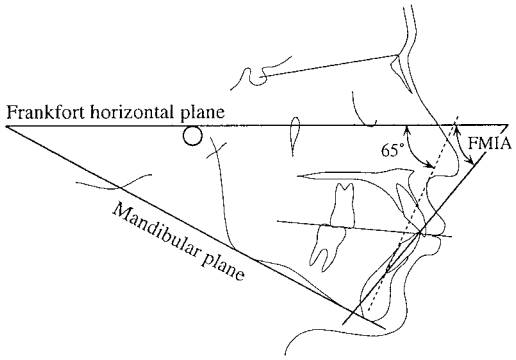

Fig. 3. Mesurement of Frankfort mandibular incisor angle (FMIA).

eter. It is placed along the dental arch between the mesial proximal surfaces of both mandibular first molars, passing smoothly over the buccal cusps of the premolars and the incisal edges of the front teeth (Figs. 1, 2). After the end of the wire with a white pencil is marked, the wire is straightened, and the marked length is measured against a scale. Tooth crown diameters of ten teeth were measured with calipers and summed to evaluate the required space (RS). If a tooth on one side was missing, its value was substituted by the size of the same tooth on the other side. The difference of the AAL and RS is called the arch length discrepancy (ALD) and is calculated as follows: ALD = AAL − RS, where ALD is the part of the discrepancy which is expressed as the crowdedness of the dental arch form. The FMIA is measured on the roentgenographic cephalogram (Fig. 3), and, if the measured values of two teeth differ, then the mean of the two values is used. The unit of the FMIA is a degree and so must be converted to a length equivalent to the protrusion of the mandibular incisors. This converted value is referred to as the head plate correction (HP) and is calculated as follows: HP = (FMIA − 65)/1.25, where HP is the other part of the discrepancy which is expressed as the forward inclination of front teeth. Finally, the total discrepancy (TD) is obtained by the formula TD = ALD + HP. Usually the values of ALD as well as the HP are expressed as minus values.

State of the third molars. Third molar state, whether erupted, half-erupted, or possibly unerupted, was recorded.

Method of analysis

The ratio difference of the discrepancy and the state of the third molars between the male and female citizens and the slaves were evaluated by Yates's continuity correction χ^2 test; the differences between measured values were examined by *t*-test.

RESULTS

The prevalences of the discrepancy were 22.2% (6/27) for male citizens, 0.0% (0/15) for female citizens, 14.3% (6/42) for all citizens, and 12.2% (10/82) for slaves (male). The prevalence of the discrepancy was higher for the male citizens than for female citizens and for slaves, but the differences among the groups were not significant.

The measured values for the discrepancy are given in Table 1. The male citizens had a slightly smaller available arch length (AAL) and larger required space (RS) than either slaves or female citizens, which means that their jaws were not big enough compared to tooth size. Arch length discrepancy (ALD) revealed no significant differences among the groups. When mean tooth size is substituted for the value of a lost tooth to gain the information from more subjects, the discrepancy of male citizens was estimated as −2.5 mm, and that of slaves was 0.0 mm, which suggests that male citizens lacked jaw space for teeth. This result agrees with the fact that male citizens show a slightly higher

TABLE 1. Quantitative analysis for the discrepancy[1]

Items[2]	Social class	Male N	Male Mean	Male S.D.	Female N	Female Mean	Female S.D.
AAL	Citizens	18	63.9	5.0	8	64.1	3.2
	Slaves	70	64.2	5.9			
RS	Citizens	9	66.2	2.0*	6	63.8	2.7
	Slaves	62	64.3	3.4*			
ALD	Citizens	9	0.5	4.3	5	0.9	3.4
	Slaves	54	0.2	6.1			
HP[3]	Citizens	29	−2.6	8.0*	13	−8.7	7.5
	Slaves	40	−2.8	7.5*			
TD	Citizens	9	−6.7	8.0	3	−9.5	9.2
	Slaves	37	−2.5	8.0			
RS[3]	Citizens	42	66.5	1.2***	29	63.5	0.9
	Slaves	186	64.1	2.0***			
ALD[3]	Citizens	18	−2.5	5.3**	8	0.8	3.1
	Slaves	70	0.0	5.7			
TD[3]	Citizens	16	−5.5	8.7	5	−6.2	9.5
	Slaves	37	−2.5	8.0			

[1] Method of Tweed (1945).
[2] AAL, available arch length; ADL, arch length discrepancy; HP, head plate collection; RS, required space; TD, total discrepancy.
[3] The values of missing teeth were substituted by the mean value of tooth size of each group.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

TABLE 2. State of third molars

	Male N	Male %	Female N	Female %
Maxilla				
Unerupted teeth				
Citizens	13/49	26.5	3/29	10.3
Slaves	68/278	24.5		
Semierupted teeth				
Citizens	2/49	4.1	0/29	0.0
Slaves	0/278	0.0		
Mandible				
Unerupted teeth				
Citizens	12/52	23.1	3/21	14/3
Slaves	41/179	22.9		
Semierupted teeth				
Citizens	3/53	5.7	0/21	0.0
Slaves	8/179	4.7		

* $P < 0.05$.

prevalence of the discrepancy than do slaves. HP was significantly smaller for female citizens than for male citizens and slaves ($P < 0.05$), indicating that female citizens had more inclined front teeth than did male citizens or slaves. Finally, the severity of the total discrepancy for all groups was marked by a negative value, signifying a lack of the space. Male and female citizens lacked twice as much as space as slaves, though there were no significant differences between the groups.

Table 2 shows that there was no significant difference between the frequencies of unerupted teeth or semierupted teeth for the male citizens and the slaves, except for the frequencies of semierupted teeth in the maxilla.

From these findings, there was a slight but not significant difference between citizen and slave social classes. Male citizens had a slightly higher frequency of the discrepancy, greater tooth size, and greater lack of space on arch length than the slaves. Female citizens had less crowding occlusion, but they had more forward-inclined front teeth, both of which indicated that citizens had a slightly larger discrepancy than male slaves.

DISCUSSION

Dietary environment and the discrepancy

The discrepancy would be expected to become increasingly severe as the economy progressed. Figure 4 plots the prevalence of the discrepancy in different populations (data sources are summarized in Table 3). In hunting-and-gathering economies such as seen among the earlier Jomon period of Japan (10,000–5,000 BP), pre-European contact New Zealand Maori (400–200 BP), and Recent Kenyans (200–100 BP), the prevalence of the discrepancy was less than 10%. Living pastoralists from around Lake Turkana, Kenya, have a 15.3% discrepancy rate (Kuroe et al., 1995), while in an agricultural economy such as the Yayoi and Kofun periods of Japan (4000–2000 BP), present-day Maori farmers in New Zealand, and modern farmers in Kenya the frequencies of the discrepancy are near to or exceed 20%. These groups depended on agriculture and were and are skilled in producing, processing, and preserving products to be more acceptable, more nutritious, and durable. In the Yedo era (400–100 BP) of Japan, when a food industry for the masses developed, the prevalence of the discrepancy was around 40%.

Among living people in Japan, the increase in the size of the discrepancy has accelerated rapidly (Inoue et al., 1986). The prevalence of the discrepancy also increases from 45.5% (N = 263) in an older adult group born between 1934 and 1936 to 59.9% (N = 495) in a younger adult group born

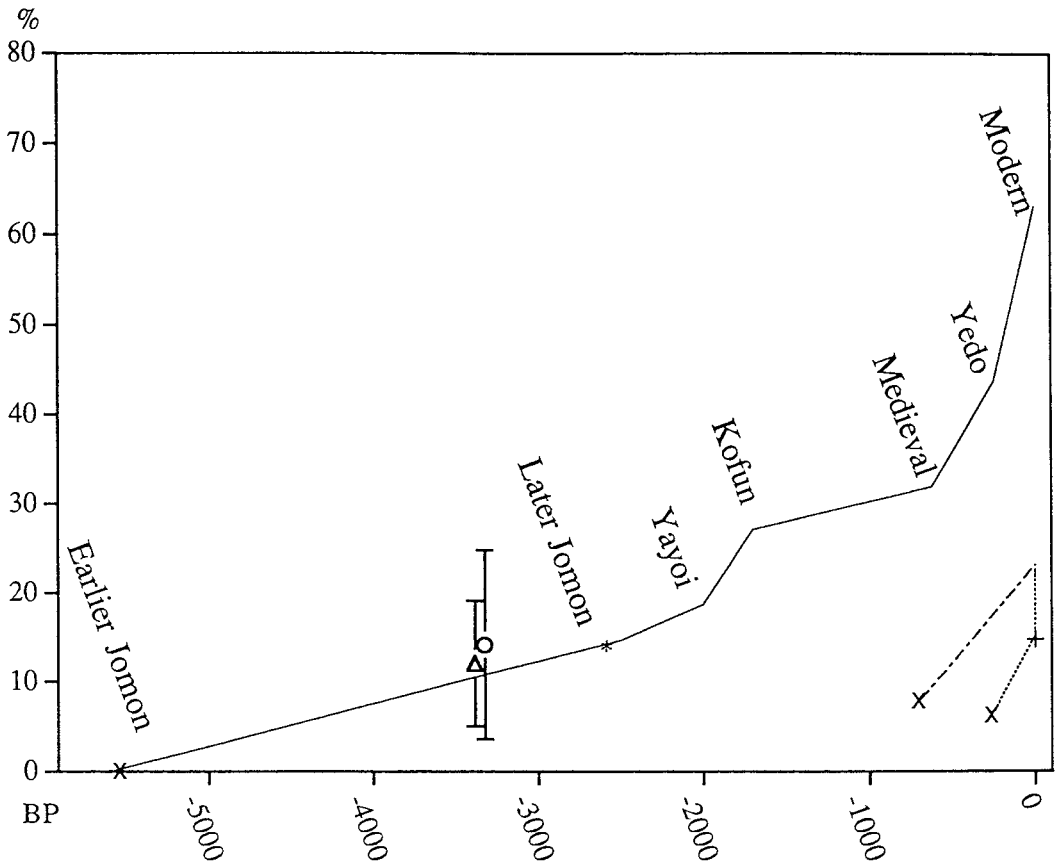

Fig. 4. Prevalence of discrepancy. ○ citizens in Yin-Shang period; △, slaves in Yin-Shnag period. Bars indicate 95% confidence limites. Over 16 years and sexes pooled. Solid line, Japanese; - — - — - — - —, New Zealand Maori; --------, Kenyan. ×, hunting gathering economy; *, mixed economy; +, bomadic economy; others, agricultural economy.

between 1964 and 1966 (Inoue et al., 1986). It is obvious that these rapid increases in the discrepancy cannot be explained by genetic factors alone, because the gene pool must be essentially the same in these groups within the Japanese population. A cause-effect relationship between diet and the discrepancy has been demonstrated even in the very short term. Further increases in modern Japan might be caused by the fact that processed foods are widespread and infiltrate diets at all ages in a family. Even a baby is targeted as a consumer. Today, the Japanese pay out a quarter of their total food budget on cooked food sold in the market (Management and Coordination Agency Japan, 1991). Most (70%) babies aged 5–8 months are fed strained baby food available on the market, and a quarter are fed this way every day (Ministry of Health and Welfare Japan, 1990).

Diet in the Yin-Shang period

The slavery of the Shang dynasty was founded on required levels of food production in the Bronze Age, and despotism was realized through widespread agricultural communes (Yang, 1986). Archaeological evidence suggests that agriculture was the basis of subsistence in the Yin-Shang period (Li, 1977, 1985). Millet, wheat, and rice were cultivated, with millet being the major source of food. Various kinds of domestic animals, such as sheep, cattle, and pigs, were also important.

TABLE 3. Summary of the previous data

Population	Location	Period	Dating (BP) in years	Livelihood	Number	Prevalence (%)	Source
Japanese	Kyushu	Earlier Jomon	10000–5000	Hunting gathering	9	0.0	Inoue et al., 1986
	Central	Later Jomon	3000–2200	Mixed	77	14.8	Inoue et al., 1986
	Kyushu	Yayoi	2200–1800	Rice agriculture	112	18.9	Inoue et al., 1986
	Central	Kofun	1800–1600	Rice agriculture	11	27.3	Hanihara et al., 1981
	Central	Medieval	700–600	Rice agriculture	50	32.0	Hanihara et al., 1981
	Central	Yedo	400–100	Rice agriculture	16	43.8	Hanihara et al., 1981
	All over	Modern	Living	Industry	495	63.1	Inoue et al., 1986
Maori	New Zealand	Recent	400–200	Hunting gathering	66	8.0	Kamegai, 1993
	New Zealand	Modern	Living	Daily farming	263	23.2	Kamegai, 1993
Kenyan	Kenya	Recent	200–100[1]	Hunting gathering	29	6.7	Kamegai, 1995
	Turkana	Modern	Living	Nomad	98	15.3	Kamegai, 1995
	Kericho	Modern	Living	Daily farming	123	22.8	Kamegai, 1995
	Nairobi	Modern	Living	Industry	112	21.4	Kamegai, 1995

[1] Include period unknown.
[2] Over 16 years and sexes pooled.

As the prevalence of the discrepancy is strongly related to the diet, the study of the discrepancy may supplement information about the diet of the Yin-Shang period. The prevalence of the discrepancy in Yin-Shang remains is around 15%, which is almost the same as that found in the later Jomon to Yayoi periods (3000–1800 BP) and among Kenyan pastoralists who live near Lake Turkana today. The transition from Jomon to Yayoi cultures marks the transition from hunting-gathering to rice agriculture in Japan. Evidence from dietary records of living pastoralists shows that they have more fiber-rich foods than do other Kenyan farmers or city dwellers. This should impose considerable loads on the masticatory system (Kuroe et al., 1995). The pastoralists base their subsistence on meat, milk, and fat from their livestock and add beans and millets from the river banks (Fedders and Salvadori, 1979; Amin et al., 1989).

Dental health also deteriorated with increasing dependence on agriculture through continued increase in food productivity and storage technology (Lukacs, 1992). The caries rate in the Yin-Shang period was low (2.2%) compared to the average for agricultural economies (Turner, 1979) or the Yayoi period (19.8%) (Inoue, 1981). In those days when sugar was not generally available, it seems that dental caries were caused by starchy carbohydrate foods. Turner (1979) has summarized the average rates of carious teeth: 1.3% (0–5.3%) in hunting-gathering economies and 4.8% (0.44–10.3%) in mixed economies, whereas in agricultural economies it reaches 8.6% (2.1–26.9%).

If all these things are taken into consideration, the diet in the Yin-Shang period might have depended more on meats than previously thought. Domesticated animals were certainly eaten. In addition, hunted animals also seem to have been eaten. To acquire slaves as well as goods, the people often fought neighboring countries. Animal hunting was still common, and in a sense it was a training for war as well as being a sport (Ching, 1990).

The social class difference

The Tokugawa family, the Shogunate, in the Yedo era of Japan (400–100 BP), must have been exposed to the most highly processed, that is, the softest diet of the time. They had a reduced jaw size and more malocclusion than did common people (Suzuki, 1985). In the case of the Yin-Shang period, there was no remarkable difference in the severity of the discrepancy between citizens and slaves, although male citizens showed a slightly stronger crowding than did male slaves or female citizens. In addition, female citizens had slightly more for-

ward-inclined teeth than did male citizens or slaves. Even though social classes in the Yin-Shang era were quite distinct (Yang, 1986), our results suggest that there were no marked differences in the diets of the two classes as far as the load on the masticatory system was concerned. It is possible that agriculture was not sufficiently intense, and thus agricultural surpluses were not enough to make a difference in the diets of different social classes. Furthermore, people might have depended more on meat than has been assumed. While grain could be ground into flour and stored, livestock could be kept alive until needed and then eaten as fiber-rich foods. It is at this point that dietary differences by social class could be expected to arise.

As for sex differences, usually females show almost the same prevalence of the discrepancy as do males (Kuroe et al., 1995) or a slightly higher prevalence than do males (Ministry of Health and Welfare Japan, 1983). It is interesting to note that male citizens more often had dental crowding than did female citizens in the Yin-Shang period, whereas female citizens had forward-inclined teeth. Crowding and forward inclination were considered to be expressions of the discrepancy, although forward inclination cannot release much discrepancy. We think that if the strength of the lip is stronger than tongue pressure, then crowding will result from the discrepancy. If it is weaker, the discrepancy will be expressed as the forward inclination of the teeth. Another possible explanation for different observations among the sexes is that society was based on patriliny in the Yin-Shang period. Male citizens had social obligations to fight to acquire slaves and goods on which the country's economy was based. Because being a warrior was thought of as very important, a man was treated better than a woman and given the "best" food, but the nature of the differences among foods was not yet extreme.

CONCLUSIONS

The prevalence of the discrepancy in the Yin-Shang period was around 15% for both citizen and slave classes. This is almost the same as the rate for the later Jomon to Yayoi (3000–2000 BP) periods of Japan and for the living pastoralists of Lake Turkana in modern Kenya. It is suggested that any dietary differences between classes were not fundamental, since the differences by social class or by sex within a class were not significant. The groups were living at a time when differences of diet between social classes were only beginning to appear, and the differential load on the masticatory system was minor.

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